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FREEZING TIMES, REWARMING TIMES, AND LOWEST TEMPERATURES IN EXPERIMENTAL FROSTBITE OF HANFORD MINIATURE SWINE

U S ARMY RESEARCH INSTITUTE
OF
ENVIRONMENTAL MEDICINE
Natick, Massachusetts

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UNITED STATES ARMY
MEDICAL RESEARCH & DEVELOPMENT COMMAND

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Technical Report

T27-87

FREEZING TIMES, REWARMING TIMES, AND LOWEST TEMPERATURES IN EXPERIMENTAL FROSTBITE OF HANFORD MINIATURE SWINE

by

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This experiment was done in 1986 as part of the U. S. Army Summer Faculty Research and Engineering Program administered by Battelle. In addition, Kansas State University has played a major role in providing support for continuation of the project. Kansas State has provided salary to the principal investigator, laboratory space, and clerical and photographic support.

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Abstract

Frostbite was produced in the skin of five Hanford Miniature Swine exposed to chilled air (-75°C) for 1, 3, 5, 10, or 20 minutes. A hypodermic probe with a copper-constatan thermocouple was inserted into the skin to monitor the temperature. Average freezing time - the time to reach 0°C, or lower - was approximately 2 minutes. The average lowest temperature for 1 minute freezes ranged from -8.3 to -9.2°C and for the 3 minute freezes ranged from -13.0 to -18.2°C. Excluding pig 5, the 5, 10, and 20 minute freezes had a smaller range, from -18.9 to -24.3. Average rewarming times were shortest for 1 minute freezes and longest for 20 minute freezes. The ranges within freezes were minimal: 2.8-3.8, 4.0-4.9, 5.0-6.3, 6.2-7.2, and 7.6-8.9 minutes(±.5 min.) for the 1, 3, 5, 10, and 20 minute freezes respectively.

Introduction

Third degree frostbite has been consistently reproduced in Hanford Miniature Swine by exposing them to chilled air ($-75^{o}C$).[1] Morphology and development of those changes have been described.[2,3] In the same experiment, freezing times, lowest temperatures, and rewarming times were recorded.

This report documents and discusses the following:

1) length of time for skin to reach $0^{o}C$ when exposed to $-75^{o}C$ air

2) lowest temperature skin reaches when frozen for 1, 3, 5, 10, or 20 minutes

3) length of time for skin frozen for 1, 3, 5, 10, or 20 minutes to rewarm to $25^{o}C$ when exposed to $25^{o}C$ air

Materials and Methods

Experimental pigs and procedures were described in detail previously.[1,2] Briefly, frostbite lesions were produced by cold air ($-75^{o}C$) delivered to 1-inch circular areas of the skin of five pigs. A hypodermic probe with a copper-constatan thermocouple was inserted into the skin, parallel to the surface for an approximate distance of 1.0 cm. Temperatures were monitored every 30 seconds. Once the thermocouple reached $0^{o}C$ or lower, the cold air was continued for 1, 3, 5, 10, or 20 minutes. At the end of that time, the skin was rewarmed with warm air ($25^{o}C$) until the computer recorded a skin temperature of $25^{o}C$.

For this report the following terms were used:

freezing time - time, to the nearest 30 seconds, for skin to reach 0°C when exposed to -75°C air.

lowest temperature - recorded during freezing skin with -75°C for 1, 3, 5, 10, or 20 minutes.

rewarming time - time, to the nearest 30 seconds, for skin frozen for 1, 3, 5, 10, or 20 minutes to rewarm to 25°C when exposed to 25°C air.

Results

Freezing times, lowest temperatures, and rewarming times for each of 40 lesions per pig (200 total) are listed in Tables 1 - 3.

Freezing time averages (Table 4) are for 40 lesions per pig. This table is small because the length of time for skin to reach freezing is unrelated to the duration it will be frozen.

Lowest temperature averages (Table 5) and rewarming time averages (Table 6) are for each duration of freeze, for each pig. Each average represents 8 lesions.

Discussion

From the time pig skin was exposed to -75°C chilled air, until it reached 0°C was approximately 2 minutes. Averages for pigs 1-4 had a narrow range of 1.9 to 2.2 minutes (±.5 min.). Pig 5 had a low average of 1.3 minutes (±.5 min.). The reason for this finding is not known. Possible explanations are that the thermocouple may have been inserted

more superficially, or the environmental or animal temperatures may have had some influence. Since the computer recorded the temperature only every 30 seconds, freezing may have occurred just after a computer recording enough times to make a difference.

As would be expected, lowest temperature a

verages became lower the longer the skin was frozen. One minute freezes ranged from -8.3 to -9.2°C and 3 minute freezes ranged from - 13.0 to - 18.2 °C. The 5, 10, and 20 minute freezes had a smaller range from - 18.9 to -24.3 °C, excluding pig 5.

The average lowest temperatures for pig 5 were consistently lower than those for the other four pigs. This finding adds support to the hypothesis that the thermocouple was probably inserted more superficially in pig 5.

Rewarming times were shortest for skin frozen for 1 minute and longest for skin frozen for 20 minutes. The shortest average thaw was 2.8 minutes ($\pm$.5 min.) and the longest thaw was 8.9 minutes ($\pm$.5 min.). The ranges within freezes were minimal for all groups.

Comments

One of the biggest drawbacks of this project was the hypodermic probe, because it was inserted manually. Any change in its depth could result in a change in temperature recorded.

Although 5 pigs is a small sample, evaluation of 200 lesions from those pigs is acceptable as a baseline. This time and temperature study should add support to histopathologic studies of frostbite.

These two studies together are the controls necessary to evaluate topical ointments used to treat or prevent frostbite.

References

1. Schoning P, Hamlet MP: Experimental third degree frostbite in Hanford Miniature Swine. Technical Report T24-87, 1987.

2. Schoning P, Hamlet MP: Experimental frostbite in Hanford Miniature Swine. I. Epithelial changes. submitted for publication, 1987.

3. Schoning P, Hamlet MP: Experimental frostbite in Hanford Miniature Swine. II. Vascular changes. submitted for publication, 1987.

4. Sharp MW, Ahle NW, Mariano RA, Sawyer W: Development of a tissue freezing and rewarming devise that uses compressed air as a medium. Technical Report T13/87:1-9, 1987.

Table 1 - Length of time in minutes (±.5min.) for skin of Hanford Miniature Swine to reach freezing when exposed to -75°C air. Each number represents a frostbite lesion.

pig 1	1.5	3	2	2	2.5
	3	2.5	3.5	2	2.5
	1.5	1	2	2.5	2
	4	2.5	2.5	1.5	2.5
	1	1	2	1.5	1
	1	1.5	1.5	1	1.5
	4	1.5	1.5	5.5	4.5
	1.5	1.5	1.5	5	1
pig 2	3	2	2	2	2
	3	3	2.5	1.5	2
	2	4	6.5	2.5	2
	1	1	1	.5	1
	2	2	1	1.5	1.5
	1	1	2.5	1.5	4
	2.5	1	.5	4	1.5
	1	1	.5	1.5	2.5
pig 3	1	2	2	1.5	2
	1.5	2.5	.5	2	4.5
	2.5	2	1.5	2.5	1.5
	1	3.5	.5	3	3
	2	1	4.5	2.5	8.5
	1.5	1.5	.5	2	1
	1.5	1.5	1	1.5	1
	.5	2	1.5	1.5	2
pig 4	1.5	1.5	5.5	5.5	1.5
	1	1	2	3	3
	1.5	6	1	3.5	1.5
	2.5	.5	2.5	2	4.5
	1.5	1	1.5	3.5	2.5
	1	1.5	.5	1	1.5
	1	1	1	.5	1
	1	.5	1	1.5	1.5
pig 5	2.5	1.5	1.5	1.5	3
	2	2.5	1	1.5	*5
	1	1	1	1	23
	.5	1	1.5	1.5	2
	1.5	1.5	1.5	1	1
	.5	1.5	1	1	1.5
	.5	1	1.5	1	2
	.5	1	1.5	.5	1

*This number was not included in calculating averages.

Table 2 - Lowest temperatures ($-^{o}C$) for skin of Hanford Miniature Swine exposed to $-75^{o}C$ air for 1, 3, 5, 10, or 20 minutes after $-0^{o}C$ or lower was recorded.

	duration of freeze (minutes)				
	1	3	5	10	20
pig 1	12.9	13.4	20.2	20.7	22.9
	7.6	14.4	15.9	27.9	18.8
	9.3	19.3	23.6	21.1	24.2
	2.9	11.1	16.7	30.8	22.8
	15.9	26.4	17.5	24.2	26.7
	7.4	15.7	15.7	23.9	30.9
	2.8	16.2	20.1	8.2	18.5
	7.9	9.9	21.5	8.7	29.9
pig 2	4.3	15.9	14.2	23.6	20.4
	6.8	9.7	18.7	24.6	20.2
	5.6	8.1	6.5	18.9	25.9
	12.2	21.4	22.0	34.2	33.7
	8.3	12.7	27.2	23.8	22.7
	11.8	22.1	14.4	23.9	14.5
	4.3	18.7	31.3	8.3	22.8
	13.9	20.6	26.4	26.0	22.9
pig 3	9.8	15.6	21.6	26.3	25.5
	9.5	13.8	21.4	18.4	13.7
	8.4	11.9	18.1	20.4	22.7
	12.6	7.0	20.0	12.8	17.1
	5.5	23.3	7.6	16.6	8.7
	10.2	11.6	27.9	18.7	30.8
	5.8	11.4	20.8	22.5	26.2
	11.0	9.6	17.7	24.9	22.1
pig 4	10.2	10.1	18.8	8.8	27.9
	13.6	16.7	19.6	15.0	16.6
	9.3	4.6	27.7	10.4	22.9
	3.8	22.1	11.6	25.6	14.7
	6.2	17.9	21.8	13.0	20.2
	11.2	17.0	20.9	31.0	27.3
	6.9	14.4	22.1	29.8	25.4
	10.7	21.6	24.4	27.0	31.7
pig 5	7.7	22.2	23.0	28.9	20.6
	7.3	10.4	27.5	28.3	31.4
	7.5	15.9	29.8	30.9	20.3
	9.2	15.0	29.3	26.5	25.7
	8.5	15.6	22.9	23.4	26.6
	7.6	13.8	26.9	32.3	24.8
	9.6	28.8	20.0	27.8	27.9
	16.5	23.5	23.3	31.6	27.1

Table 3 - Length of time in minutes (±.5min.) for skin of Hanford Miniature Swine frozen for 1, 3, 5, 10, or 20 minutes to rewarm to 25°C when exposed to 25°C air.

	duration of freeze (minutes)				
	1	3	5	10	20
pig 1	3	4.5	8	6.5	9.5
	3.5	4.5	7.5	7.5	8
	3.5	3.5	5	6.5	7
	6	5.5	7.5	7.5	10.5
	3	4	6.5	5.5	7
	3.5	3.5	6	6.5	9
	5	3.5	4	8	10.5
	3	4	5.5	9.5	10
pig 2	3.5	4.5	5	6	9.5
	3.5	4	5.5	5.5	7.5
	2.5	5	5.5	5	6
	2.5	3.5	5	5.5	8.5
	3	4	4.5	6	5.5
	2.5	4	6.5	9	10
	3.5	3.5	4.5	8	12
	2.5	3.5	3.5	10	12
pig 3	3	6	6	7	9.5
	2.5	5.5	4	4.5	5.5
	3.5	4.5	5	6.5	5.5
	3	7	5.5	10	12
	2.5	3.5	5.5	5	6
	3	4.5	5	7.5	8.5
	3	4	5	9	10
	2	4.5	6.5	9	12.5
pig 4	3	5	7.5	8	8
	2	4.5	6	8	6
	2.5	5	4	4	5
	4.5	4.5	6.5	9.5	12.5
	3	3.5	4.5	7	6.5
	3	4.5	6	6.5	9
	2.5	4.5	6	7	7
	3	4	5	10	16
pig 5	5	6.5	6.5	5.5	6
	4.5	4.5	5.5	5.5	6.5
	2.5	4	4.5	5.5	4
	3	4.5	6	7.5	11
	3.5	4.5	5	5.5	6.5
	1.5	5.5	5	7	7
	2.5	5	6	6.5	9.5
	2	4.5	5	6.5	10.5

Table 4 - Freezing time averages in (minutes ±.5min) for skin of Hanford Miniature Swine to reach freezing when exposed to -75°C air.

	minutes
pig 1	2.2
pig 2	2.0
pig 3	2.0
pig 4	1.9
pig 5	1.3

Table 5 - Lowest temperature averages (-°C) for 1, 3, 5, 10, or 20 minute freezes in 5 Hanford Miniature Swine exposed to -75°C air.

	duration of freeze (minutes)				
	1	3	5	10	20
pig 1	8.3	15.8	18.9	20.7	24.3
pig 2	8.4	16.2	20.1	22.9	22.9
pig 3	9.1	13.0	19.4	20.1	20.9
pig 4	9.0	15.6	20.9	20.1	23.3
pig 5	9.2	18.2	25.3	28.7	25.6

Table 6 - Rewarming time averages in (minutes) (± .5min.) for 1, 3, 5, 10, and 20 minute freezes in 5 Hanford Miniature Swine exposed to -75°C air.

	duration of freeze (minutes)				
	1	3	5	10	20
pig 1	3.8	4.1	6.3	7.2	8.9
pig 2	2.9	4.0	5.0	6.9	8.9
pig 3	2.8	4.9	5.3	7.3	8.7
pig 4	2.9	4.4	5.7	7.5	8.8
pig 5	3.1	4.9	5.4	6.2	7.6